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A method for evaluating Lean Assembly process at Design stage

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Abstract

Lean product design has the potential to reduce the overall product development time and cost and can improve the quality of a product. However, it has been found that no or little work has been carried out to provide an integrated framework of 'lean design' and to quantitatively evaluate the effectiveness of lean practices/principles in product development process. This research proposed an integrated framework for lean design process and developed a dynamic decision making tool based on Methods Time Measurement (MTM) approach for assessing the impact of lean design on the assembly process. The proposed integrated lean framework demonstrates the lean processes to be followed in the product design and assembly process in order to achieve overall leanness. The decision tool consists of a central database, the lean design guidelines, and MTM analysis. Microsoft Access and C# are utilized to develop the user interface to use the MTM analysis as decision making tool. MTM based dynamic tool is capable of estimating the assembly time, costs of parts and labour of various alternatives of a design and hence is able to achieve optimum design. A case study is conducted to test and validate the functionality of the MTM Analysis as well as to verify the lean guidelines proposed for product development.

Keywords

Manufacturing Assembly Process; Lean Design Guidelines; Methods Time Measurement (MTM); Integrated Lean Decision Tool

1 INTRODUCTION

Competitive advantage for many manufacturing companies now lies in their ability to effectively implement on-going product and process innovation, superior manufacturing, continual improvement of quality and reliability (Q&R) of existing products and developing a continual stream of quality new products [1, 2]. Moreover, market pressures have forced companies to emphasise cost, speed, quality, agility, flexibility and most importantly leanness of their manufacturing facilities [2, 3]. These can only be accomplished by developing and producing quality products and bringing them to the market quickly at a reasonable price, in order to meet or exceed customer expectations. As a result, manufacturers' are forced to implement new and efficient strategies in their manufacturing operations. Some of the established strategies in this context are lean practices/principles. Lean strategies/principles in product design have the potential to reduce the overall product development time and cost and can increase the quality of a product. Because "Lean Products start with Lean Design" [4] and design process is the very important part of product development process. According to Shetty [5], at least 75% of the product costs are committed by the end of the conceptual design phase. This means that decisions and changes made after this time can influence only 25% of the product's manufacturing cost. According to Cloke [4]; "Investment on quality and cost reduction at the design stage is 100 times more cost effective than investment after production begins". Keys [6] reported that some 75-90% of opportunity to influence the entire product development cost is gone by the time a design is released to production and assembly. As a result, decisions made during initial concept development can inevitably fix many of the critical cost factors of a product and hard to significantly reduce manufacturing and assembly costs later on. It is also recognized that not paying enough attention to product design early in the product life cycle potentially result in inefficiencies (wastes) throughout the product development (PD) process [7]. In product development, manufacturing and assembly are the major activities that combine the components into final product. Design for Assembly methodologies were developed to help the designer to develop an efficient and economic product so that costs of assembly is reduced. Vincent Chan [8] defined Design for Assembly as "a process for improving product design for easy and low-cost assembly, focusing on functionality and on assemblability concurrently". However, it has been found that no or little work has been carried out to provide an integrated framework of 'lean design' and to quantitatively evaluate the effectiveness of lean practices/principles in product development process. The aim is to concentrate early in the design stage on creating products are easy to assemble, before much effort and cost is expended in pursuing another design, which might be unnecessary expensive. There have several methods to calculate efficiency of Assembly process. The Boothroyd Method [9] is based on parts reduction and handling and insertion improvement. But it is only useful for redesign of existing products, and not to use for conceptual design of new products. The Hitachi Method [10] calculates design efficiency based on the insertion process only, while the Lucas method is focused on a reduction of the number of parts. The most complete calculation of design efficiency is provided by the MTM analysis. It determines design efficiency that takes into account parts reduction and handling, orientation, and insertion improvement. Moreover, it is possible to evaluate the redesign of existing products as well as the conceptual design of new products. For these reasons the MTM analysis is used to implement as a Design for Assembly Method in the Integrated Lean Design Framework.

Therefore, this research proposed an integrated framework for lean design process and developed a dynamic decision tool based on Methods Time Measurement (MTM) approach for assessing the impact of lean design on the assembly process. A central database, the design for assembly guidelines, MTM Analysis and programming language C# are used to generate the integrated lean design framework as a complete user friendly decision tool. The proposed central database includes: list of preferred parts, tools and utilities, reusable design elements, lean design guidelines for assembly and product lifecycle, the effects and benefits of application of design for assembly guidelines as well as how these guidelines influence other parts of the whole product lifecycle. The developed MTM Analysis tool is used to estimate the impact of the application of these guidelines on the assembly process concerning time for this assembly process, costs of involved parts and labour costs. MTM analysis tool also showed that the application of 'Lean Design for Assembly Guidelines' guides the designer towards a product with an optimum number of parts that requires simple, cost-effective assembly operations and the most appropriate manufacturing processes and materials for its components. Finally, a case study is conducted to test and validate the functionality of the MTM Analysis as well as to verify the effect of using the 'Lean Design for Assembly Guidelines' on the assembly time and costs.

The rest of the paper is structured as follows: Section 2 provides a systematic integrated lean design framework, MTM analysis; a performance evaluation tool is presented in Section 3. Research findings are discussed in Section 4. Limitations and extensions of this work round out the paper.

2 INTEGRATED LEAN DESIGN FRAMEWORK

A number of models that describe the content of lean production have been evolved; such as the Karlsson & Ahlström model [11]. The most of these models describe the lean thinking in the procurement, manufacturing, and distribution but ignore the product design process. To achieve low-waste and high-velocity new product development process is the most critical step in making a company lean and maximizing their revenue and profit potential. The main aspects of this 'lean product development process' are a continuous-flow development process and waste elimination. Figure 2 shows the proposed integrated lean design framework and method of evaluating the assembly process at design stage.

The first step is to define the new product as clearly as possible the market and customers desire on performance, features, and quality. During this step, Voice-of-the customer tools are applicable. Because, value of a product can only be defined by the ultimate customer, and it's only meaningful when expressed in terms of a specific product (a good or a service, and often both at once) which meets the customer's needs at a specific price at a specific time. The next step is to establish the Product Line Optimization Team and the Multi-disciplinary Design Team. The first task of this team is to consider how the new product will fit within existing material inventory, processes, factory layout, core competencies, etc.

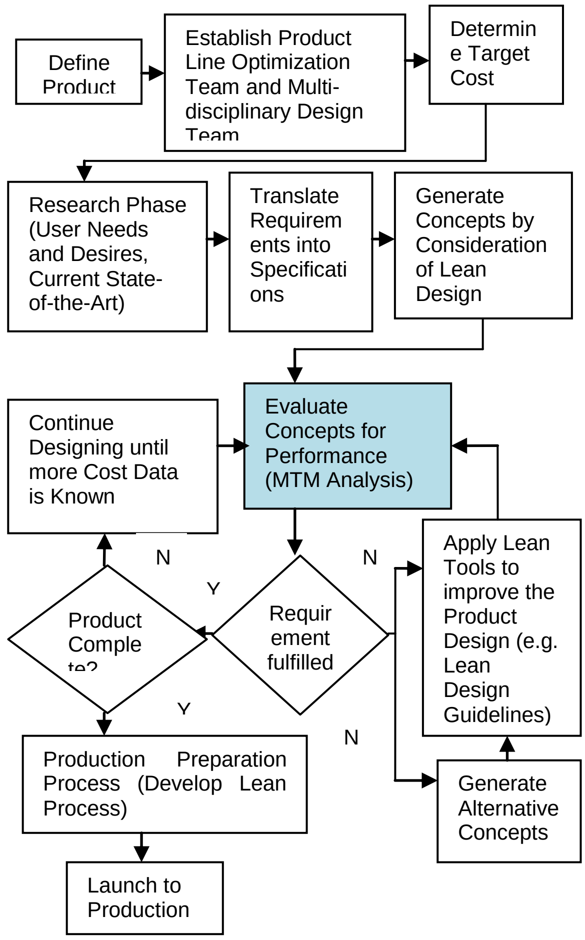

Figure 2: Integrated lean design process framework

The design team develops a preliminary cost model to determine the target cost and generates a broad and innovative list of design concepts for the new product. Therefore, the team has to translate the given requirements into product specifications. To evaluate the concepts and to determine which concept has the best combination of production cost and customer value, the design team uses a cost/performance trade-off tool. In this research, MTM analysis is used as the part of this tool and utilized design for assembly method to rate the assembly cost for a product. To optimize design variables, the team uses lean design guidelines such as Lean Design for Life Cycle Guidelines. In addition to the guidelines, designers need to understand more about their own and the suppliers production system in order to develop company unique lean design guidelines to further guides, for example, specific manufacturing processes, capabilities and limitations. All these guidelines are stored in a structured database as a reference work for the design engineers.

Lean design for Life Cycle includes 'Lean Design for Assembly', 'Lean design for Manufacturing', 'Lean design for Testability', Lean design for Safety', 'Lean Design for

Reliability', 'Lean Design for Service and Maintenance', 'Lean Design for Environment', and 'Lean Design for Disassembly' [4, 12-14]. The final step in the Lean Design process before product launch is the Production, Preparation, and Process, also called 3P. This process is to ensure a smooth and rapid transition of the new product design into the factory, by consideration of tact time, workplace-layout, process capacity, etc. This 3P will ensure a lean production and incorporate error proofing and Just-in-Time. Moreover, it will guarantee process capabilities and cycle times and build quality into the system.

3 MTM ANALYSIS: A PERFORMANCE EVALUATION TOOL FOR LEAN ASSEMBLY PROCESS

Methods-Time Measurement (MTM) is a predetermined time and motion system and can be used to suggest what types of parts should not be used and how parts as well as assembly process can be redesigned to reduce assembly time. The time unit for a MTM motion is described as Time Measurement Unit (TMU; 1 TMU = 0.036 sec) [15]. The entire MTM Analysis includes eleven different basic motions to describe any manual operation or method [15]. In this research, the seven basic MTM motions are specified, which are necessary for the use of the MTM Analysis in the integrated lean design process as a tool to estimate the time and cost for assembly of products. These motions have been simplified and adapted to the requirements of the integrated framework [15]. Time Data Tables and the Decision Models for each kind of motion are taken as the basic framework for the implementation of the MTM Analysis [15]. Using the MTM, an electric switch gear design is analysed, and after consideration of the Lean Design for Assembly Guidelines later redesigned. The following steps have to be done to analyse a product with the MTM analysis:

- Select a product to be analysed by MTM analysis tool
- Update the central product development database using the user interface to update the product information
- Start a new or open an existing MTM Analysis
- Select the correct Work Station
- Create the Part List
- Create the Tool List
- Edit the Position Matrix
- Edit the Grasp Matrix
- Edit the List with all Performances

4 DEMONSTRATION OF PROPOSED METHODOLOGY BY A CASE EXAMPLE

The case study is a simplified representation of a real situation in a company. The proposed methodology described in section 2 is presented here by a case example. This case example origins from "Design for Product Success" written by Devdas Shetty [5]. It has been used and adapted for the intention to illustrate the functions of the integrated lean design framework and implementation of MTM analysis. Initially, an electric switch has been selected for MTM analysis. A multi-disciplinary design team has been formed and this team includes people from design, production, assembly, and supply chain department. The structure of the switch gear is determined by this team based on the user needs and desires (VOC). Then, these requirements are converted into product specifications. The existing design for the switch contains of 18 parts, as seen in Table 1. This design uses a lot of different parts, screws and springs. Most of the time screws are used to join parts instead of snap-fit fasteners. Moreover the hand and tool access is not sufficient for joining the parts without a hidden point or a regrasp. The material cost determined by the design team for the original electric switch is altogether 13.82 AUD$. All prices for parts, tools, utilities, and materials are estimated to describe the function of the implemented MTM analysis.

Table 1: Components of the original electric switch

Part Name	Quantity	Thickness [mm]	Size [mm]	Price [AUD$]
Switch Base	1	15	29	1,99
Terminals	3	9	8	0,33
Centre Terminal Contact	1	6	8	0,59
Terminal Screw	3	7	7	0,25
Contact Rocker	1	4	22	0,49
Base Cover	1	3	29	1,19
Switch Plunger	1	4	16	1,39
Switch Spring	1	3	20	0,99
Switch Toggle	1	9	35	1,55
Mounting Cover	1	13	19	1,99
Mounting Hardware	1	2	16	1,09
Terminal Screw Short	3	7	4	0,21

4.1 Select or Update Basic Data in the Central database

The first step to analyse a product with MTM is to generate the basics for the object in the program module in Basic Database. These include information about the article categories, work station, parts, and tools, utilities and materials, pay grade (Figure 3). In this case, pay grade is the basis for the calculation of the labour costs in the MTM analysis. The electric switch is assembled at the work station 1 with a pay grade of 35 AUD$ per hour. The part number and the part name are the unique identifiers and can only be used for one part, which prevents duplicate identifiers. To define a new tool an article category, 5-digit part number and name are necessary. For additional information, it is possible to add the price, weight and dimensions, as well as a specific description. For the analysis of the original switch two types of containers and one assembly jig (mechanical stop) are determined.

4.2 Start a new or open an existing MTM Analysis

After the completion of all appending basic data, the analysis of the product with the MTM method can begin. The first step is to identify a product and define the assembly process to be analysed by developed MTM analysis tool. In the developed MTM tool, one can start a new MTM analysis by entering the name in the appropriate text box. In this module, it is also possible to open an existing analysis or to delete a no longer needed analysis (Figure 4).

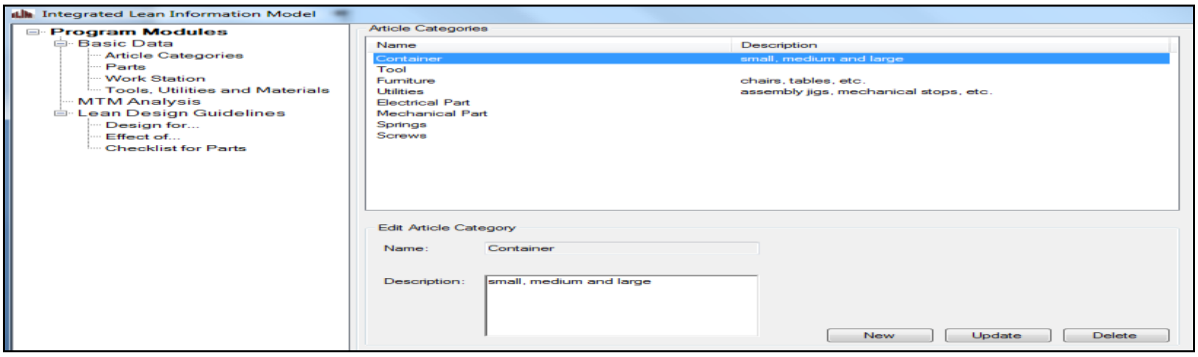

Figure 3: MTM Analysis for original electric switch

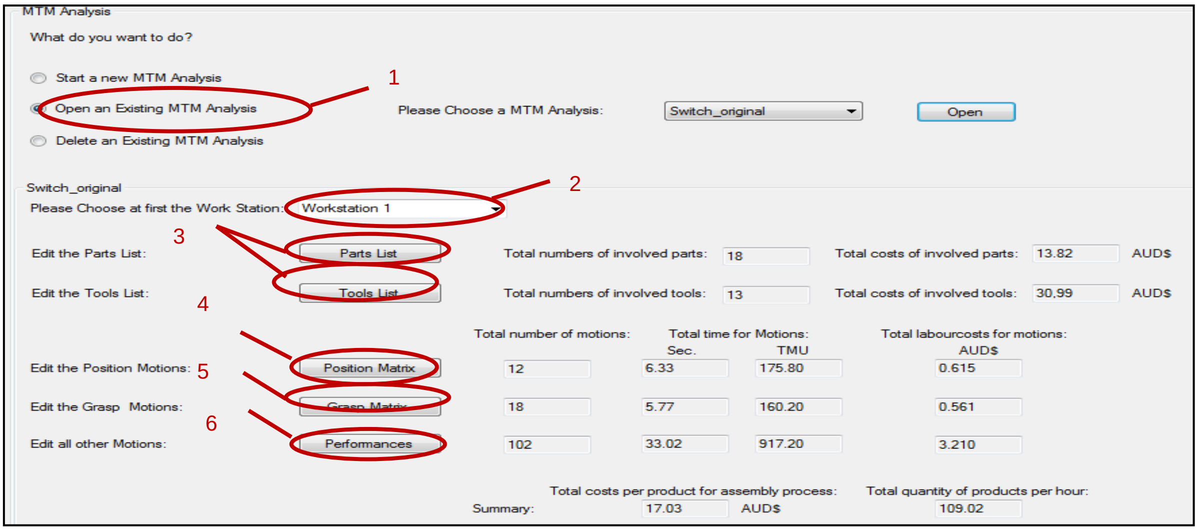

Figure 4: MTM analysis of original electric switch

4.3 Select the correct Work Station

Every MTM analysis should start with the selection of the correct work station for producing a product, because this will be the basis for the calculation of the product and labour costs of a product (Figure 4). Assemble of different parts of a product can be done in the several workstation and labour cost of these work station may not be same. By clicking in the combo box a context menu will open with the defined work station in the basic database. In this case, work station 1 is selected for performance analysis of the original electric switch.

4.4 Create the Part and Tool List

The compilations of the necessary parts and tools list are the next steps in the analysis. Therefore, just click on the appropriate button for selecting defined parts or tools for making the specific product. If an item is necessary then checked by clicking the item, the program will add this article to the part or tool list. To remove items out of the list just uncheck these in the lower list view. Moreover, the total number of involved parts and tools as well as their total costs will be on display in the MTM main window. In this case, the total number of involved parts for making the original electric switch are 18 and their material costs per product are 13.82 AUD$. The tools include eight small containers and four medium containers as storage areas for the parts as well as one assembly jig (Figure 4).

4.5 Edit the Position Matrix

After creating the parts and tools list, the real analysis of the product starts with the first matrix 'Position Matrix' (Figure 4). This matrix describes all position motions are conducted in the assembly process. If the user clicks on the button Position Matrix a separate window with a matrix consisting of all included parts will appear. A click with the right mouse button in the appropriate cell will open a context menu with the menu items:

- Add Position Motion – Add a new motion
- Delete Position Motion – Delete an existing motion
- Disable Position Motion – Disable a no longer needed motion, the cell colour will be grey
- Enable Position Motion – Enable a disabled motion

There will be several position positions in the database. From these position motions, user has to select the appropriate case for the position motion which includes 'Case of Symmetry', 'Class of Fit', 'Design for Shaft and Hole', and the number of motions. With all these information, the program will calculate the time for this position process on the basis of the time data described by [15] and write this time in TMU in the selected cell in the position matrix. After the completion of all necessary position, the program summates all position motions and their times and shows these in the main form to the right of the button Position Matrix. To assemble the original electric switch, twelve position motions are needed with a total time of 175.80 TMU or 6.33 sec. Moreover, the program calculates the labour costs for these motions about 0.615 AUD$.

4.6 Edit the Grasp Matrix

The analysis with the Grasp Matrix runs similar to the Position Matrix (Figure 4). A separate window with a matrix consisting of the tools in the rows and the parts in the columns will be open. After the selection of the type of grasp the cases for every type will be displayed, for example the cases for the type select and the program summates all grasp motions and their times as well. For the assembling of the original electric switch 18 grasp motions has to be needed with a total time of 160.20 TMU or 5.77 sec. The total labour costs for these motions amounts to 0.561 AUD$ per product.

4.7 Edit the List with all Performances

In the Performance List, all motions included in the assembly process will be described with their time and labour costs (Figure 4). The program automatically will transfer the determined position and grasp motions matrix into the performance list. The user has to put these motions in the right order. Additional motions can be added to this list by clicking the right mouse button in a cell. After this action a context menu will open with the following menu items:

- Add Motion – Add new disengage, grasp, move, reach, release, or turn motion
- Delete Row – Delete a complete row from list
- Disable Motion – Disable a no longer needed motion; the cell colour will be grey
- Enable Motion – Enable a disabled motion
- Add new Row – Add a new empty row to the list
- Add Parts/Container/Tools – Add in this special process included parts, tools, or utilities to the list

If the user wants to append in the process included parts or tools, in the lower part of the form will display two list views with all defined parts, tools, utilities, and materials. Similar to the part or tool list it is possible to add or delete these articles in the concerning cells by checking and un-checking respectively. The user has to select the appropriate types and classes and press the button Analyse. The program will calculate according to the time data tables the time in TMU and the labour costs in AUD$.

4.8 MTM analysis Results of original electric switch

The assumptions for the analysis of the original electric switch are that the average distances to the containers are determined as 20 cm and that the parts are jumbled with other objects in a group so that search and select occur. The screw movement is simply described as two 180 degree turn motions separated by a regrasp. The assembly process of the original electric switch consists of 102 separate operations and according to the MTM analysis takes 917.20 TMU or 33.02 sec. By selecting the Workstation 1 with a pay grade of 35.00 AUD$ per hour the total labour costs for all motions are 3.210 AUD$. All involved times, costs, and counts as well as the improvements are shown in Table 2.

5 PROPOSED REDESIGN OF ELECTRIC SWITCH

The goals of redesigning the switch are to minimize the number of parts, reducing the time for assembly process and increasing the safety and ergonomics for the work people during the assembly process, while maintaining the functionality of the original design. The electric switch has been redesigned based on the proposed integrated lean design framework. As a result, following design changes have been occurred on the electric switch.

First: The switch base was modified to incorporate a snap-fit into the switch cover. This eliminated the existing bent tabs used on the metal switch cover to attach it to the plastic switch base. Moreover, there are snap-fit sockets to hold two metal wire clinch terminals and the centre terminal / rocker in place. All these modifications will not cause additional fabrication charges for this piece because a new plastic mold has to be created.

Second: The wire clinch terminals replace the terminals, terminals screws short and terminal screws of the original switch. They perform the dual function of holding the stranded wires and providing contact points for the centre terminal/rocker. Wires are held in place within terminals by a metal-locking spring action. The two wire clinch terminals are formed from rolled brass sheets and they snap into the plastic switch base. Additional tooling and fabrication charges are incurred to create these specialized parts.

Third: The centre terminal/rocker replaces the centre terminal contact, centre terminal screw short, contact rocker and switch spring of the original design. This piece snaps into the plastic switch base, like the wire clinch terminals. It is formed out of brass and sheet metal and provides a flexible interface at the switch toggle. This part incurs extra tooling and fabrication charges.

Fourth: The plastic switch toggle was modified extensively from the original design. A molded plastic piece with snap-fit posts replaced the cast aluminium piece. The plastic design of the new toggle incorporates the original switch plunger piece into the toggle itself. No extensive charges are foreseen in fabrication of this new part because a plastic-mold part simply replaces the casting process.

Fifth: The switch cover underwent an extensive redesign. It replaces the base cover, mounting threads, and mounting cover of the original design. This piece undergoes a complicated fabrication process. The overall shape is a metal casting, and several machining operations are performed to finish the part. This makes the switch cover one of the most expensive parts in the new design. But the new design allows a snap-fit at the switch base interface, and posts on the toggle snap into the inner diameter of the threaded portion.

Sixth: The mounting hardware is not changed from the original design. The switch assembly is redesigned to keep the same functionality as the original design. This includes the way that it is mounted to the electrical panel, chassis, etc.

5.1 MTM analysis for the Redesigned electric switch

To compare these two design proposal of the electric switch and to estimate the better design concerning costs and assembly time a MTM analysis has been conducted for the redesigned product. The selected work station is also

Workstation 1 with a wage per hour of 35 AUD$. Thus, these two design principles can be evaluate about the same basics. The proceeding is equivalent to the analysis of the original switch. The user has to enter the position operations are involved in this assembly process. In this analysis, manufacturer needs to edit the part and tool list, position matrix, grasp matrix, and the list with all performances. The following table displays the complete MTM analysis for the redesigned electric switch. The similar assumptions of original electric switch are also considered for this analysis. After analysing by MTM tool, it has been found that the assembly process of the redesigned electric switch consists of 42 separate operations and takes according to the MTM analysis 435.60 TMU or 15.68 sec. All involved times, costs, and counts as well as the improvements are shown in Table 2.

Table 2: Comparison of two electric switches

Performances	Original Electric Switch	Redesigned Electric Switch	Impro vement [%]
Part Count	18	7	61,1
Costs of involved Parts [AUD$]	13,82	11,55	16,4
Tool Count	13,00	6,00	53,8
Costs of involved Tools [AUD$]	30,99	10,00	67,7
Position Operations Count	12	6	50,0
Position Operations Time [sec]	6,33	5,68	10,3
Labor Costs of Position Operations [AUD$]	0,615	0,552	10,2
Grasp Operations Count	18	7	61,1
Grasp Operations Time [sec]	5,77	2,1	63,6
Labor Costs of Grasp Operations [AUD$]	0,561	0,204	63,6
All Performances Count	102	42	58,8
All Performances Time [sec]	33,02	15,68	52,5
Labor Costs of all Performances [AUD$]	3,21	1,524	52,5
Total Cost per Product [AUD$]	17,03	13,07	23,3
Products per Hour	109,02	229,59	110,0

6 CONCLUSION

The lean design guidelines for product life cycle have been developed to support engineers/designers in designing easy and cost-effective products. These guidelines consolidate manufacturing knowledge and present them to the designer in the form of simple rules to be followed when designing a product. All these guidelines are stored in a structured central database as a reference work for the design engineers. The developed MTM analysis tool demonstrated that the application of these guidelines during an early stage of the design process reduce the time to market, reduction in part counts and costs, improvements in quality and reliability, reduction in assembly time, as well as reduction in manufacturing cycle time. The design changes in the case example 'original electric switch' showed that application of lean design guidelines lead to a faster and more efficient assembly of the electric switch. Further analysis of this research may find benefit in a more in-depth study of guidelines across several industry types, using this research as background. It is expected that the proposed integrated lean design framework and developed MTM analysis would make a significant contribution to lean product development process of any manufacturing organization.

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